

Status of GaAs Solar Cell Production

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Summary

This paper reviews recent experience in producing GaAs solar cells, to meet the full requirements of space-array manufacturers. The main problems have been in extending MOCVD technology to provide high throughput of high quality epitaxial layers, and to integrate the other important factors needed to meet the full range of user requirements. Some discussion of evolutionary changes is also given.

Introduction

GaAs cells were intensively studied in the laboratory and later in a AF MANTECH Program. The latter program was extended (before the program was completed to meet the needs of a space-array application).

Although the basic technology steps had been identified, considerable adjustment was needed to provide continuous throughput with consistent quality, also meeting all the detailed requirements of the user.

This paper surveys some of the production areas which have been resolved in the past few years.

User Needs

For spacecraft use, several criteria have been developed to define solar cell performance.

The first area of interest is to ensure that the cells have the specified power output, especially after exposure to the radiation fluences expected in orbit. This involves selecting a cell design and processing sequence which provide consistent electrical performance and reasonable resistance to degradation from charged particle radiation.

For GaAs cells, these features are mostly determined by controlling the MOCVD growth conditions, with some influence from the quality of the substrate and of its surface properties. The most important factors lie in the tradeoffs needed to achieve the correct layer quality and uniformity in a reactor which can provide sufficient throughput under continuous use. Demonstration that these factors could be well controlled was achieved by processing consistently larger areas of GaAs substrates (about 1000 cm² per reactor) than was considered practicable a few years ago.

The second area of attention involves the post-growth cell processing. This is mostly application of suitable contacts but also involves deposition of the coatings along with several other steps included to meet specific concerns of the users.

The contacts must provide consistently low contact resistance to the active layers and must also fulfill user requirements—good bondability, and good stability under specified environmental stressing. The front contact system must also be combined with effective grid formation methods. The contact adhesion must be high to adapt to array-laydown techniques.

The third area of interest involves special concerns of the users. These concerns vary for different missions, but may include additional attention to cell ruggedness to allow ready combination into the array laydown methods, precautions to reduce cell degradation from solder-leakage (if soldered contacts are required), checking that the cells can withstand periodic shading without degradation. Also this area includes conforming to all the mechanical and visual specifications.

Last, the cells must qualify under the specified set of environmental stresses (temperature cycling, UV exposure, moisture exposure).

The following section demonstrates that most of these user needs have been filled by the present GaAs production processes.

Production Cell Performance

Present throughput is in excess of 350W/week which provides more than 18 KW per year. Median efficiency levels have risen steadily, and now range from 17.5% towards 18.5%. Figure 1 shows wafers of GaAs and Ge, and solar cells of different configurations made on those wafers.

Individual process step yields have also been increased and are monitored by a computer system. Contact pull strengths have also been increased. All contact pulling strength (for both front and back contacts) exceeds stringent space solar cell requirements.

Product Development

The GaAs space solar cell line has been expanded into other product variations.

The first of these involved a limited production run, under tight deadlines to deliver about 40% of the high efficiency GaAs cells used on the GM/Hughes Sunrayer Car. These cells were specified as space-like components. The average AM0 efficiency was 17.7%, corresponding to AM1 efficiencies over 20%. The histogram of AM0 efficiency of these production 2 × 4 cm GaAs solar cells is shown in Figure 2.

Also, the grown layers used for space cells have been combined with carefully designed grid contacts to give cells with high efficiency under high concentration (up to 500×, AM1 efficiencies about 24%, AM0 efficiency 20%). Figure 3 shows an enlargement of the Cassegranian cell produced by ASEC.

ASEC has also begun partial switchover to use of Ge substrates following four years of development work on these structures with the Ge wafer thinned to around 3 mils. Physically these cells look similar to regular GaAs/GaAs cells. However, they have slightly different I-V curves, based on photoactive junction between the GaAs and Ge. Hence, higher open-circuit-voltage values for

GaAs/Ge solar cells are typically observed. The light I-V curve of a 2×4 cm GaAs/Ge solar cell is shown in Figure 4. A very impressive AM0 efficiency of 20.5% was obtained from this GaAs/Ge solar cell. The other photovoltaic parameters are as follows:

1. V_{oc} -1.187V
2. I_{sc} -240.8mA
3. CFF-77.7%

Several minor changes in the established GaAs production sequence are needed to provide efficient GaAs/Ge cells.

First, suitable Ge substrates must be specified and obtained.

Next the MOCVD growth conditions must be slightly modified to ensure good quality GaAs layers are grown (reduce interface imperfections such as antiphase formation), and also to provide the best interfacial junction conditions.

The AR coating is also similar with fine-tuning to provide best current matching for the GaAs and Ge regions.

Conclusions

GaAs solar cells have been produced at high throughput with well controlled properties. Efficiencies and stability have been demonstrated for users. Present work is aimed at diversifying to include Ge substrates and at the same time, to reduce costs. High costs arise from expensive material costs, and particularly from the high costs needed to purchase and maintain the MOCVD reactors. Nevertheless, the feasibility of high throughput production of reliable, high efficiency GaAs cells on either GaAs or Ge substrates has been well proven.

GaAs and Ge wafers, and a Range of Cells

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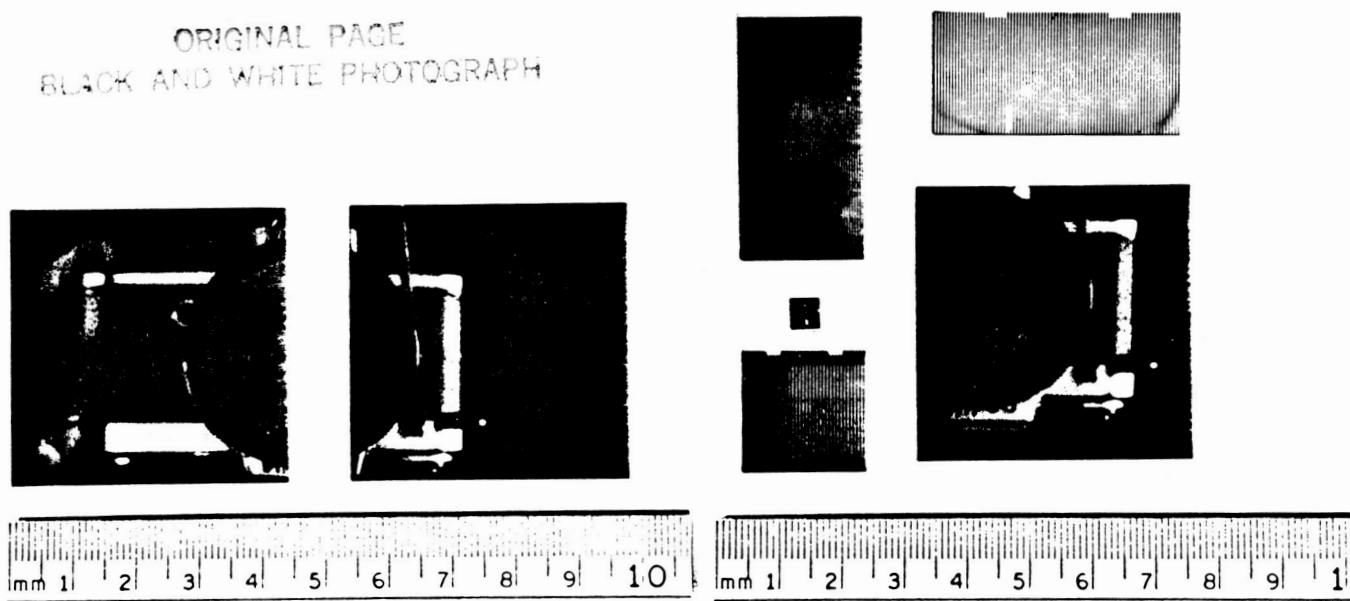
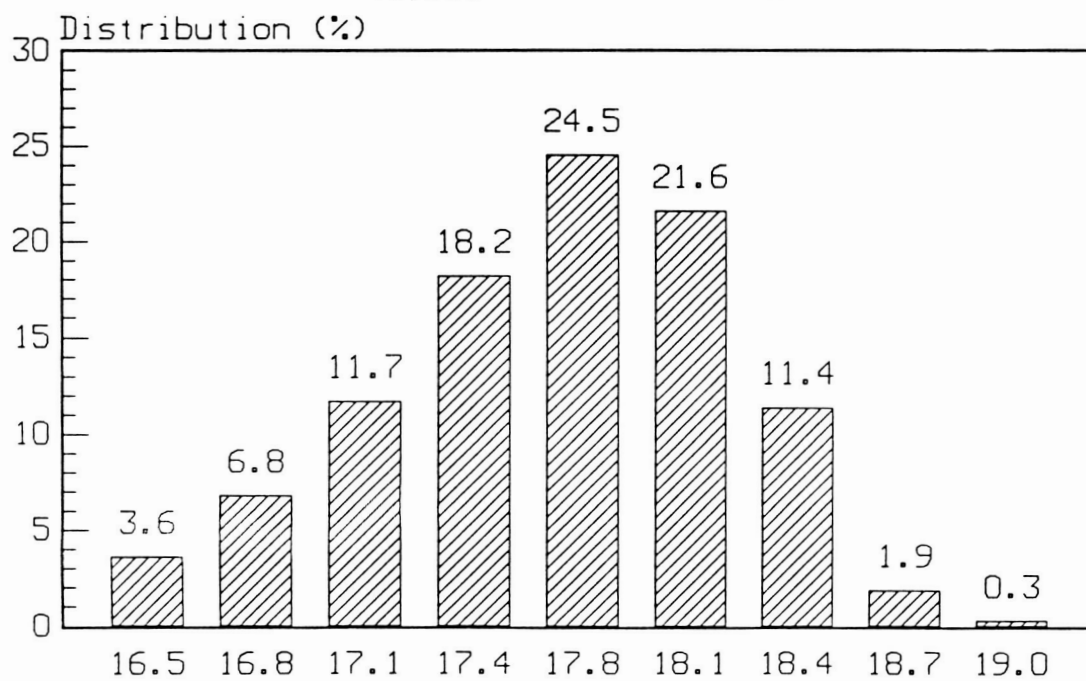


Figure 1

Histogram of AMO Efficiency
of 2x4 GaAs Solar Cell
(5,300 CIC Assemblies)



Efficiency (%)
Figure 2

C-41

An enlargement of the Cassigranian GaAs Solar Cell

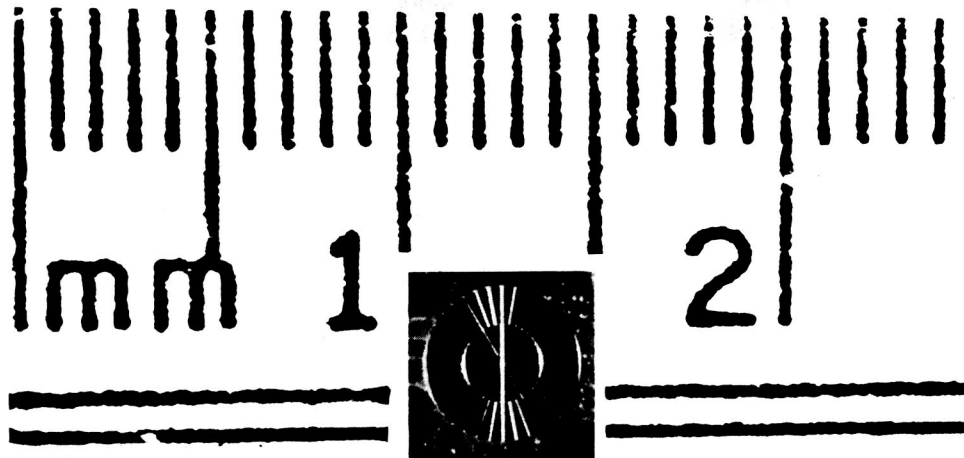


Figure 3

The Light I-V Curve of a 2x4cm GaAs/Ge Solar Cell.

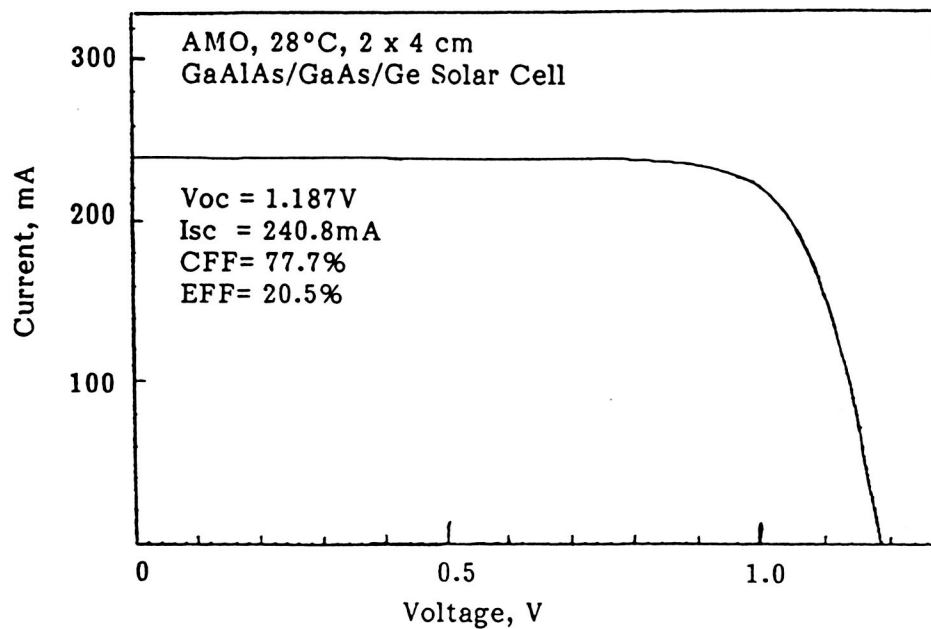


Figure 4